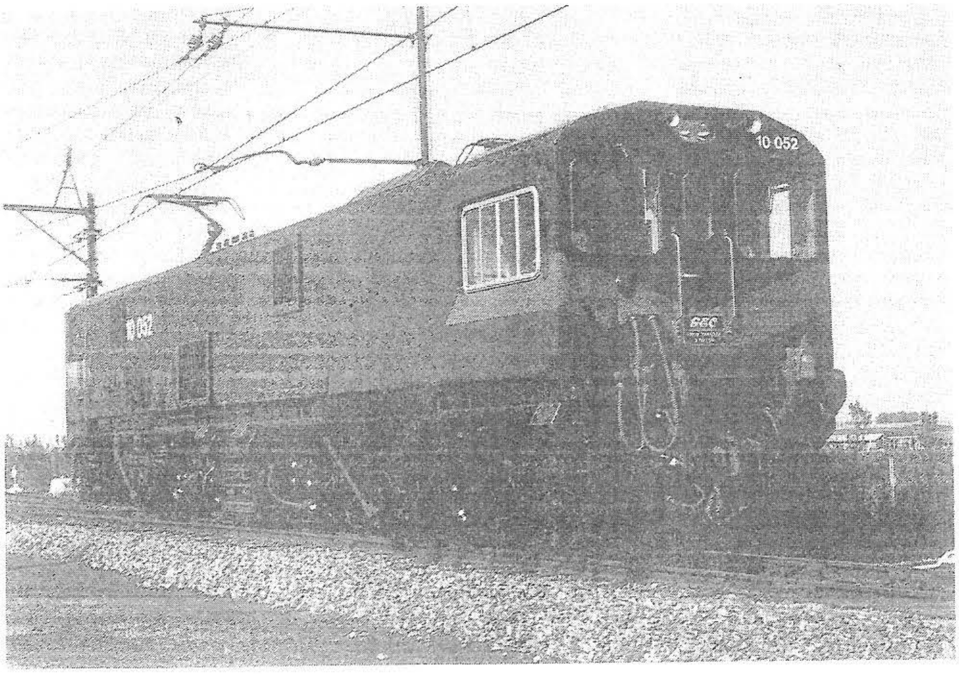
AN ELECTRONIC FREIGHT LOCOMOTIVE

N.C. Jones, J.H. McNeil, S.C.S. Royle

GEC Transportation Projects Limited, GEC Traction Limited, U.K.

The Class 10E1 is a 3000kW, 126 tonne, 6 axle locomotive for operation on any part of the South African Railways 3kV dc, 1065mm gauge system. A typical duty is to haul 10000 tonnes with 4 locomotives on a line with a maximum gradient of 1%. There are many state of the art features, consistent with modern practice as described by Mercado (1).



PERFORMANCE

The reasons behind the choice of performance are described by Nicholson (2). The locomotives operate over a voltage range of 2 to 4kV, have a starting tractive effort of 450kN (37% adhesion) and a continuous tractive effort of 310kN. The control system maintains the performance characteristic over the entire speed range, 0 to 90km/h, irrespective of wheel diameter.

A blended regenerative and rheostatic electric braking system provides a maximum braking effort of 195kN over the speed range 41 to 17km/h. There is a continuous braking power of 2187kW at the rail above 41km/h. Dependent on the receptivity of the overhead line the braking energy is either returned to the supply or dissipated in forced air cooled resistor banks, one for each bogie, which are continuously rated for the maximum braking power.

MECHANICAL PARTS

The body and underframe is an integral, all welded steel fabrication. The structure is designed to withstand a buffing load of 3000 kN applied at the locomotive couplers and is also of sufficient strength to allow the complete locomotive to be lifted from the ends. The strength of the structure was verified by strain gauge testing on the first completed body shell.

Bogie

The 3 axle cast steel bogie is a development of that used on the South African Class 7E locomotives. Traction and braking forces are transmitted through inclined low level traction links which minimise weight transfer effects within the bogie. The motors are arranged in tandem which also helps to minimise the effects of weight transfer.

The bogie is connected to the body at the pivot which incorporates a wear sleeve of ultra high molecular density polyethylene and the side bearers are lined with PTFE to minimise turning forces.

Modular brake units are used with a single brake cylinder operating a composition brake block on each wheel. This eliminates the need for brake rigging between axles on the bogie. A lever operated hand brake is fitted in the No.2 cab and operates on the bogie at that end of the locomotive.

TRACTION MOTORS

The type G425AZ motor is a 4-pole machine having a continuous rating of 900V, 645A, 546kW, 774rev/min. The armature is lap wound and both fields and armature are insulated to Class H. The axle-hung nose-suspended motor, drives through a single reduction gear train with a ratio of 17/87. The fabricated motor frame is partially laminated.

POWER CIRCUIT

Armature Converters

The armature converters use the GEC standard "three thyristor" design, described by Whiting(4). Power is provided separately to each of two bogie groups via 860A, 3kV choppers connected on the negative side of the motors. Each chopper controls a bogie group of three separately excited dc traction motors connected in series.

Traction Motor Field Supply System

The fields for a bogie group are connected in series. Their supply is derived from the motor alternator set. To improve the power factor and reduce waveform distortion the alternator output for each field group is full-wave rectified and then controlled by gate turn off thyristors (GTO's).

A separately excited traction motor scheme allows flexible locomotive control but can suffer from supply voltage transients. To overcome this potential problem the field drives were made "four quadrant", enabling the field current to be forced up and down in forward and reverse. The field drive can produce over three times the necessary voltage for full field current in either polarity. Thus the field responds very quickly. There is of course no need for any electro-mechanical switching for direction control.

Since a separately excited scheme is used there is no need for any special field excitation system while in electric brake. The system response under fault conditions is fast enough not to need a high speed circuit breaker (HSCB) in the electric brake circuits. Should the overhead line become short circuit when in full regenerative brake, a rate of fall of line voltage detection system will quickly force the field excitation off. Under these conditions the locomotive is disconnected from the line and the power converters inhibited.

Electric Braking

The locomotive is designed to hold laden trains descending the long gradients on the South African Railway System, a duty that can last for several hours. For braking duty the armature group is electro-mechanically reconnected across the 3kV chopper and the field current reversed. With the fields excited, the choppers transform the armature voltage up to that of the overhead supply. Providing the overhead supply is receptive all the brake energy is regenerated. However, if the overhead supply approaches 4kV then energy is diverted into the brake resistor stack.

Operating the armatures at a lower voltage than the overhead supply, imposes a consistent performance that has the characteristics of a rheostatic brake, even when fully regenerating as described by Hennelly(5). As the proportion of regenerated to rheostatic energy is calculated each chopper cycle, any overhead interruptions (pantograph bounce) do not affect the locomotive performance in any way. This is an important consideration for the handling of long freight trains with high drawbar forces.

MICROPROCESSOR CONTROL SYSTEM

The microprocessor control system uses an 8086 (16 bit) microprocessors, and four 8031 (8 bit) microcontrollers. The 8086 microprocessor has overall control of the system, with the 8031 microcontrollers operating in pairs to control the armature and rheostatic choppers, one pair to each motor group.

Each 8031 processor pair controls an armature chopper. One 8031 (the servo processor) controls analogue to digital conversions, and calculates the required chopper on-times in response to this data and the demand from the 8086 processor. This processor performs some overload monitoring and will directly trip the main HSCB under fault conditions.

The second 8031 (the pulse generator) in the pair takes the on-times passed from the servo processor and generates the required thyristor firing pulse trains.

The data is passed between the two 8031s and the 8086 processor by a shared random access memory (a three port RAM). Checks are made between the processors to ensure that the data is valid. This mutual cross checking acts as a software watchdog, and should any one of the three processors develop a problem, the others can detect it and take the appropriate action.

Earlier builds of this class of locomotive, by another company, had a large number of low voltage control relays. As described by Scrooby (3), it was policy to reduce the number of relays to a practical minimum, by incorporating much of the logic previously performed by relays into the software. The additional overhead on the microprocessors is not large. All the power circuit overload protection, except for the primary overload, is performed solely by the processor systems.

CONTROL SCHEME

The multiple operation of up to 6 locomotives requires close tolerance effort/speed characteristics, with continuously variable driver demands. The characteristic is a series motor type, with field weakening. Full use is made of the microprocessors to control the motors so as to mimic series motors.

Within a consist the locomotives will perform uniformly in response to the pulse-width modulated (PWM) driver's demand signal.

Motoring

The field current is controlled to maintain the motor voltage, at a value set by driver demand and line voltage. At low speeds a field current limit is reached. This limit depends on the driver demand, and the wheelsize of the group.

At high speeds, when operating in constant motor voltage mode, wheelsize compensation is not required. This is because the strategy controls the power to the motors.

The armature current is controlled independently of the field. The armature current reference is a non-linear function of speed and driver demand. Look up tables are used to generate this reference.

Weight transfer The control system modifies the armature demand. The leading bogie has its armature demand reduced by 6.5% whilst the trailing bogie is increased by 6.5%.

Wheelslip On detecting a slip the armature current on the slipping motor group is rapidly ramped down to minimum demand, and held there until the wheel has re-adhered. On re-adhering the demand is quickly ramped up to 82% of the armature current present at the start of the slip, and then slowly to the demand value.

This creates a wheelslip correction system, which will adapt to the rail conditions, and make use of the available adhesion. Together with automatic sanding this eliminates any need for driver intervention. The system is capable of correcting slips at maximum torque whilst stationary within 0.5 revolutions.

Braking

The control scheme in electric brake is very similar to that used in motoring. The field current is controlled to a value depending on driver demand, speed, and wheelsize, subject to a motor voltage limit. This limit is set depending on speed to maintain the power limit of the motors, and brake resistors.

Rheostatic Control The transition from full regenerative to full rheostatic brake is made very quickly without disturbance to the system. The armature current reference is calculated from the measured armature voltage so as to follow Ohm's Law. Thus the armature current is the same for full rheostatic or regenerative brake. The rheostatic choppers are controlled in open loop by the filter capacitor voltage, and its rate of rise.

Wheelslide The wheelslide correction is carried out by reducing the field current, which will reduce the motor voltage, and hence the armature current. If the armature current was reduced artificially then the Ohm's Law relationship between the motor voltage and armature current would not be maintained. This would leave the system vulnerable should a line transient occur. Since the field current can be forced off, a fast correction can be obtained.

Fault Logging

A fault logging system needs to be flexible, and simple to use if it is to cater for the different requirements placed on it during the life of the locomotives. The logging requirements whilst commissioning locomotives might be quite different from those when the vehicles have been in service for some time.

This system continuously records analogue data values, such as currents, and voltage levels. When a fault condition occurs the system will log further sets of analogue data. It will then record status data, i.e. fault type, time, date, driver demand, speed, and fault indications to the driver.

A hand held terminal is used to communicate with the electronics frame on the vehicle. This terminal allows the operator to perform several operations on the fault log through a series of menus. This includes setting the real time clock, retrieving the logged data, altering the logging parameters, and clearing the data.

Once the data has been transferred to the terminal it can be examined, or transferred to a PC and analysed later, using proprietary graphic software packages if required.

ELECTRONIC CONTROL SYSTEM TEST FACILITIES

Manual Sequence Control

Maintenance staff are able to stimulate the outputs from the electronics via a portable terminal, independently to the normal control software. This simplifies testing of the locomotive.

A series of menus offer various options to the operator. Thyristor firing pulse patterns can also be generated without the locomotive being live. The system will also display the state of the inputs, both digital and analogue values.

Test Box

A portable test box is used which can test the electronics frame in-situ, or stand alone as required. This test box can test the frame, record the results, and offer advice to the operator as to the best course of action. This offers an excellent first line maintenance facility.

AUXILIARY CIRCUITS:

To realise the benefits of relatively inexpensive and readily available induction motors, 380V, 3-phase, 50Hz is generated by the motor-alternator (MA) set, which is fed from the 3kV dc overhead supply.

The alternator voltage output is regulated by control of the exciter field. Frequency is regulated by control of the speed of the MA set by weakening or strengthening the motor series field as appropriate. The motor series field is strengthened by injection. To weaken the field, and thus increase the motor speed, an inductive divert is introduced.

The MA set comprises a 4-pole double commutator drive motor with a controlled series wound field system and a 4-pole 3-phase alternator with brushless exciter. All the rotating parts are mounted on a common shaft.

LAYOUT OF EQUIPMENT

The principle of the layout is for functional grouping, ease of maintenance and minimum cabling and piping. A central corridor gives ease of access to the equipment.

The main power converter equipment cases are located at diagonally opposite corners of the compartment and are adjacent to the line filter and motor series inductor. A centrifugal fan provides cooling air for the inductor and chopper case as well as the three traction motors on each bogie.

A separate centrifugal fan discharges filtered air into the body to pressurise the locomotive and generally cool the other items of equipment.

Software Considerations

A microprocessor allowed much more complex, and adaptive logic to be used. The flexible nature of software meant that correct management of the project was essential. Many people over estimate the ease with which software can be modified. Generating, and documenting software is expensive. The microprocessor system, and its response to all conditions, must be fully specified before detail work commences.

Diagrammatic representation of Software

The software control function had to be represented in a manner readily understood by non-software engineers.

Flowcharts were not chosen as they do not readily represent the system as a "black box" for maintenance engineers to understand the control detail.

In this project a logic representation was chosen using AND, OR gates etc. This meant showing the serial decision process of the processor in a parallel logic form and in cases of complex logic accuracy was sacrificed for simplicity of representation.

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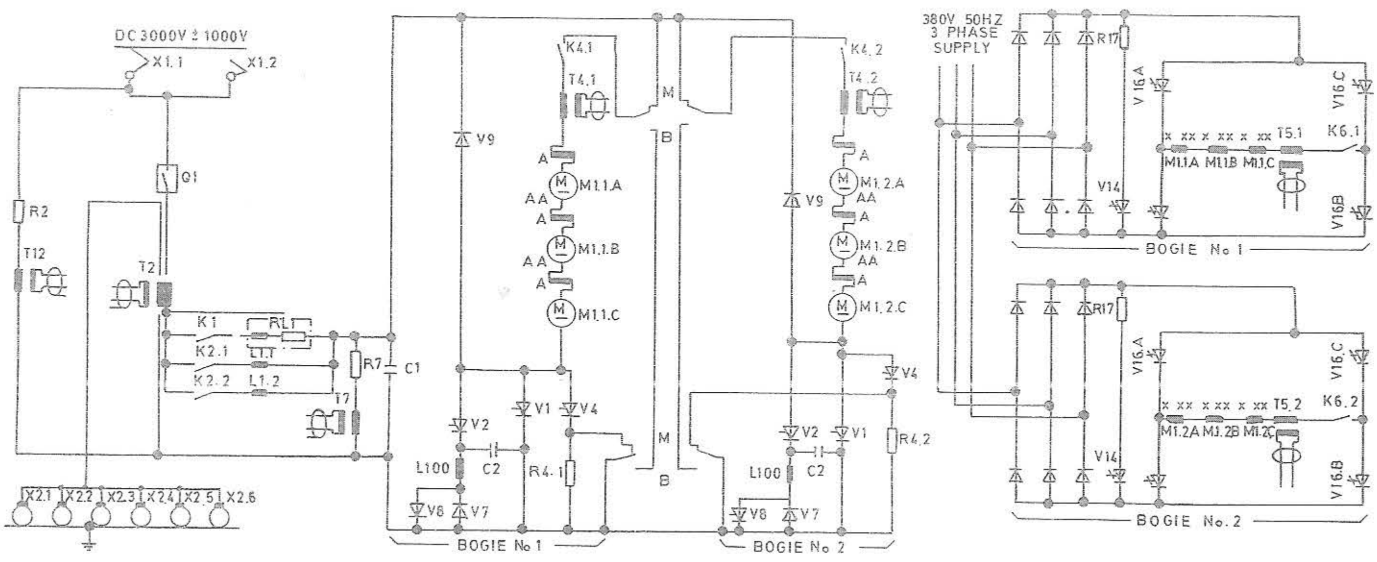
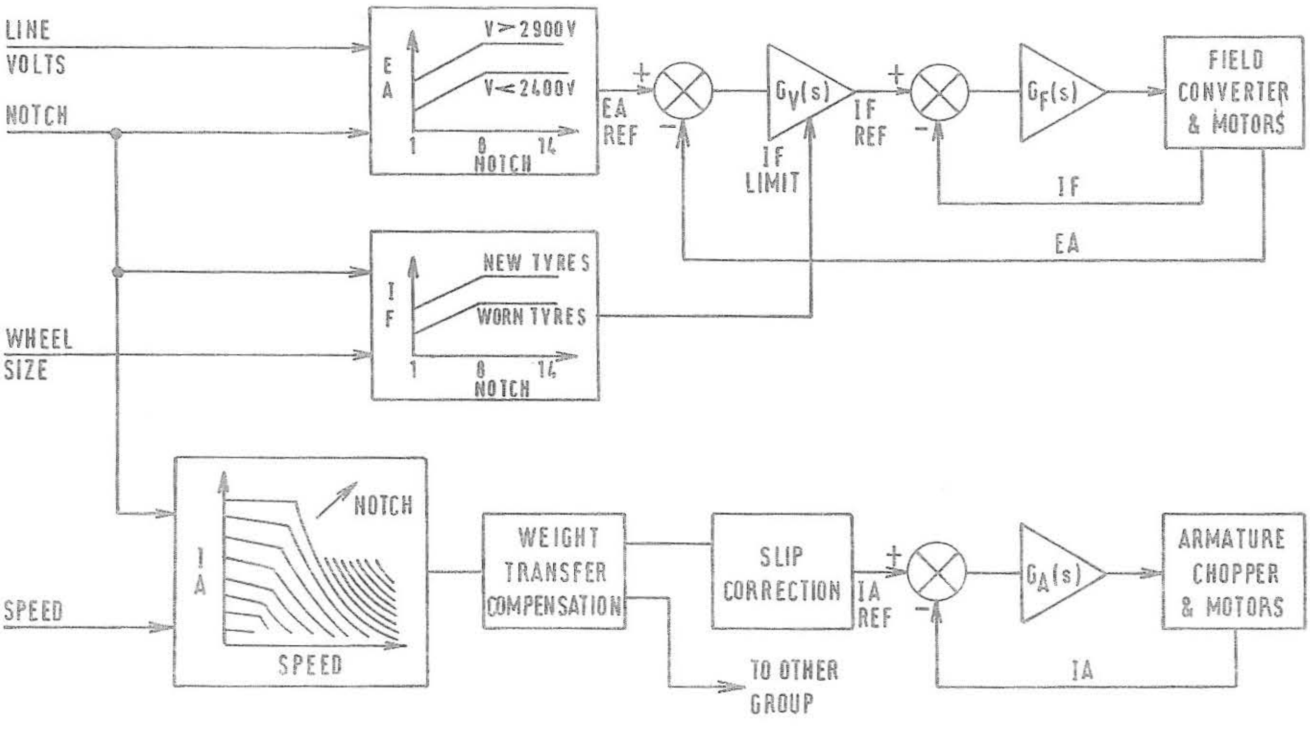
SYMBOLS

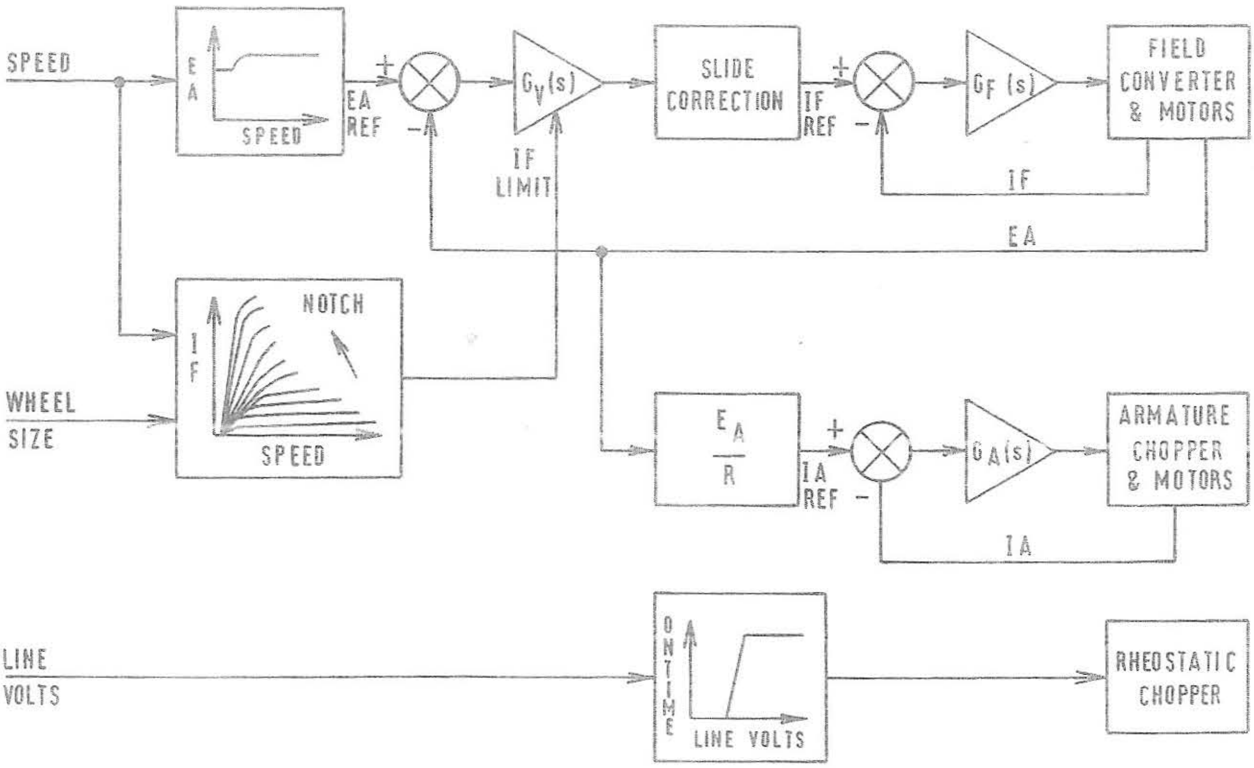
EA	-	Motor voltage
EA REF	-	Motor voltage demand
G (s)	-	Armature control servo function
G (s)	-	Field control servo function
G (s)	-	Voltage control servo function
IA	-	Armature current
IA REF	-	Armature current demand
IF	-	Field current
IF REF	-	Field current demand
R	-	Brake stack resistance



POWER CIRCUIT SCHEMATIC



MOTORING CONTROL SCHEME



BRAKING AND RHEOSTATIC CHOPPER CONTROL SCHEME